VOLTAGE MODE OTRA MOS-C SINGLE INPUT MULTI OUTPUT BIQUADRATIC UNIVERSAL FILTER

Rajeshwari PANDEY[1], *Neeta PANDEY*[1], *Sajal Kumar PAUL*[2], *Ajay SINGH*[1], *Balamurali SRIRAM*[1], *Kaushlendra TRIVEDI*[1]

[1]Department of Electronics and Communication Engineering, Delhi Technological University, Main Bawana Road 42, Delhi, 110 042, India

[2]Department of Electronics Engineering, Indian School of Mines, Dhanbad, 826 004, Jharkhand, India

rajeshwaripandey@gmail.com, neetapandey06@gmail.com, sajalkpaul@rediffmail.com, ajaysingh1990.ece@gmail.com , sriram1990dce.ec@gmail.com , kaushaltr.dce@gmail.com

Abstract. *In this paper, an Operational transresistance amplifier (OTRA) based MOS-C voltage mode single input multi output (SIMO) biquadratic universal filter configuration is proposed. The configuration is made fully integrated by implementing the resistors using matched transistors operating in the linear region. It exhibits the feature of orthogonal controllability of angular frequency and quality factor through gate bias voltage. The non-ideality analysis of the circuit is also given. Workability of the universal filter is demonstrated through PSPICE simulations using 0,5 μm CMOS process parameters provided by MOSIS (AGILENT).*

Keywords

Analog signal processing, OTRA, SIMO, universal filter.

1. Introduction

Recently the OTRA has emerged as an alternate analog building block since it inherits all the advantages offered by current mode techniques. The OTRA is a high gain current input voltage output device. The input terminals of OTRA are internally grounded, thereby eliminating response limitations due to parasitic capacitances and resistances at the input. Several high performance CMOS OTRA topologies have been proposed in literature [1], [2], [3], [4], [5] leading to growing interest in OTRA based analog signal processing circuits. In the recent past, OTRA has been extensively used as an analog building block for realizing a number of analog signal processing and generation circuits such as immittance simulators [6], [7], [8], [9], oscillators [10], [11] multivibrators [12], [13] and filters [1], [14], [15], [16], [17], [18], [19], [20], [21], [22]. Many voltage-mode biquadratic filters using OTRA were proposed in the literature that can be classified as single input and single output (SISO) [1], [13], [14], [15], [16] multi-input single output (MISO) [17], [18], [19], and single input multi output (SIMO) [1], [20]. However, only one standard filter function can be obtained at a time in each filter realization of SISO and MISO category. In SIMO configuration with only one input, multiple filter functions may be obtained simultaneously. A detailed comparison of these structures is given in Tab. 1 which reveals that no OTRA based SIMO structure is available in the literature that provides all five standard responses simultaneously. In this paper, a voltage-mode OTRA MOS-C universal biquadratic SIMO filter based on ref. [1] is presented which realizes all the standard filter functions; namely lowpass, highpass, bandpass, notch and allpass, simultaneously. The proposed structure puts no restriction on the input signal in contrast to the structures reported in [18], [19], [20]. Additionally the earlier reported structures require either change of component type [14], [17]or removal of components [1], [22] for realizing various filter responses. However, the proposed circuit does not require a change in component type/ removal of components. It simply poses matching condition on component values for notch and all pass responses. The proposed OTRA MOS-C universal biquadratic SIMO filter employs five OTRAs, twelve resistors and two capacitors. It also enjoys the feature of orthogonal controllability of angular frequency, quality factor and filter gain. All resistors are implemented using MOS transistors operating in the linear region. This not only makes filter electronically tunable but also consumes less chip area. The function of proposed filter has been confirmed by SPICE simulations.

2. Circuit Description

OTRA is a three terminal device, shown symbolically in Fig. 1. Its port relations are characterized by the

Tab.1: Comparison of the proposed work with the previously reported work.

Ref.	No. of inputs	Simultaneous Outputs	Standard filter functions available	Condition		No. of OTRA	No. of passive components (C/R)
				On Input Signal	On component Selection		
[1]	One	Two Three One	LP,BP LP,HP,BP LP,HP,BP,NF,AP	No No No	No No Yes	Two Three Two	Two / Four Two / Six Two / Five
[14]	One	One	LP,HP,BP,NF,AP	No	Yes	One	LP: Two /Three HP: Three/ Two BP: Two / Two NF,AP: Three/ Three
[15]	One	One	LP, BP	No	No	Two	Two / Four
[16]	One	One	AP	No	No	One	First order AP: One/Three Second order AP: Two / Four
[17]	One	One	AP,BR	No	Yes	One	1st order AP: One/three or Two/Two; 2nd order AP,NF: Three / Three
[18]	four	One	LP,HP,BP,NF,AP	Yes	Yes	Two	Topology1:Five/Four Topology2:Six/Four
[19]	Three	One	LP,HP,BP,NF,AP	Yes	Yes	One	Four/Four
[20]	Two	One	LP,HP,BP,NF	Yes	No	Two	Three/Four
[21]	One	Three	LP,HP,BP	No	No	Three	Two/Six
[22]	One	One	LP,HP,BP,NF,AP	No	Yes	Three	Two/Eight
Proposed work	One	Five	LP,HP,BP,NF,AP	No	Yes	Five	Two/Twelve

following matrix.

$$\begin{bmatrix} V_p \\ V_n \\ V_O \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_O \end{bmatrix}. \qquad (1)$$

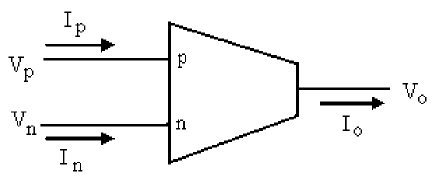


Fig. 1: OTRA circuit symbol.

For ideal operations, the transresistance gain R_m of OTRA approaches infinity and forces the input currents to be equal. Thus, OTRA must be used in a negative feedback configuration. The proposed filter is shown in Fig. 2. Routine analysis of the circuit of Fig. 2 results in the following transfer functions:

$$\frac{V_{01}}{V_{in}} = \frac{s^2 G_1 C_1 C_2}{D(s)}, \qquad (2)$$

$$\frac{V_{02}}{V_{in}} = \frac{s G_1 G_4 C_2}{D(s)}, \qquad (3)$$

$$\frac{V_{03}}{V_{in}} = \frac{G_1 G_4 G_6}{D(s)}, \qquad (4)$$

$$\frac{V_{04}}{V_{in}} = \frac{\frac{G_7}{G_9} s^2 G_1 C_1 C_2 + \frac{G_8}{G_9} G_1 G_4 G_6}{D(s)}, \qquad (5)$$

$$\frac{V_{05}}{V_{in}} = \frac{G_1}{D(s)} \cdot \left(\frac{G_{11}}{G_{12}} \left(\frac{G_7}{G_9} s^2 C_1 C_2 + \frac{G_8}{G_9} G_4 G_6 \right) - \frac{G_{10}}{G_{12}} s G_4 C_2 \right), \qquad (6)$$

where $D(s) = s^2 G_3 C_1 C_2 + s G_4 G_5 C_2 + G_2 G_4 G_6$.

Equations (2)–(4) clearly indicate that high pass, band pass, low pass responses are available at V_{01}, V_{02}, and V_{03} respectively. Band reject response is available at V_{04} as given in (5), with BR gain (G_{BR}) $= G_1/G_3$, if

$$G_7 = G_9, \; G_1 G_8 = G_2 G_9. \qquad (7)$$

An allpass response is available at V_{05}, as expressed in (6) with allpass gain (G_{AP}) = G_1/G_3, if

$$G_1 G_{10} = G_5 G_{12}, G_7 G_{11} = G_9 G_{12}, G_1 G_8 G_{11} = G_2 G_9 G_{12}. \qquad (8)$$

The high pass gain (G_{HP}), band pass gain (G_{BP}) and the low pass gain (G_{LP}) are respectively given by

$$G_{HP} = G_1 / G_3, G_{BP} = G_1 / G_5, G_{LP} = G_1 / G_2. \qquad (9)$$

The resonant angular frequency (ω_0) and the quality factor (Q_0) are given by:

$$\omega_0 = \sqrt{\frac{G_2 G_4 G_6}{C_1 C_2 G_3}}, \qquad (10)$$

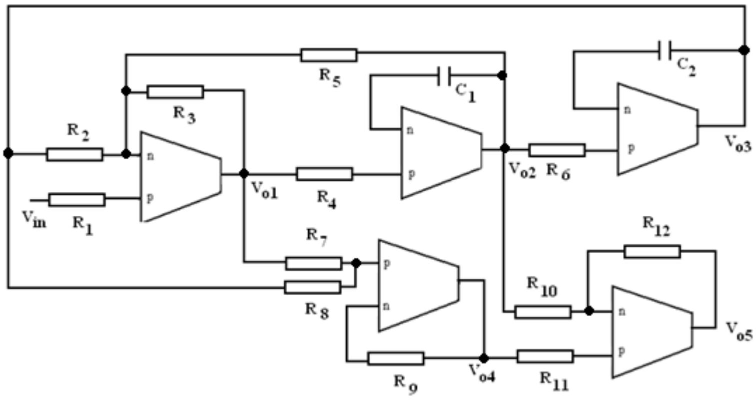


Fig. 2: Proposed biquadratic universal filter.

$$Q_0 = \frac{1}{G_5}\sqrt{\frac{G_2G_3G_6C_1}{C_2G_4}}. \tag{11}$$

This suggests that the Q_0 can be independently controlled by varying R_5 without affecting the ω_0. It can be noted from (10) that simultaneous adjustment of R_2 and R_4 results in orthogonal tuning of ω_0. Also, the filter gain can be controlled through R_1 without affecting ω_0 and Q_0.

The sensitivities of ω_0 and Q_0 with respect to each passive component are low and obtained as

$$S_{R2}^{\omega_0} = S_{R4}^{\omega_0} = S_{R6}^{\omega_0} = \frac{1}{2}, S_{R3}^{\omega_0} = S_{C1}^{\omega_0} = S_{C2}^{\omega_0} = -\frac{1}{2}. \tag{12}$$

$$S_{R5}^{Q_0} = -1, S_{R2}^{Q_0} = S_{R3}^{Q_0} = S_{R6}^{Q_0} = S_{C1}^{Q_0} = \frac{1}{2},$$

$$S_{C2}^{Q_0} = S_{R4}^{Q_0} = -\frac{1}{2}. \tag{13}$$

It is well known that the linear passive resistor consumes a large chip area as compared to the linear resistor implementation using transistors operating in the linear region. The differential input of OTRA allows the resistors connected to the input terminals of OTRA to be implemented using MOS transistors with complete non-linearity cancellation [1]. Figure 3 shows a typical MOS implementation of resistance connected between negative input and output terminals of OTRA. The resistance value may be adjusted by appropriate choice of gate voltages thereby making filter parameters electronically tunable. The value of resistance so obtained is expressed as

$$R = \frac{1}{\mu_n C_{ox}(W/L)(V_a - V_b)}, \tag{14}$$

where μ_n, C_{ox}, W and L are electron mobility, oxide capacitance per unit gate area, effective channel width, and effective channel length of MOS respectively which may be expressed as

$$\mu_n = \frac{\mu_0}{1+\theta(V_{GS} - V_T)}, \tag{15}$$

$$C_{ox} = \varepsilon_{ox}/T_{ox}, \tag{16}$$

$$W = W_{drawn} - 2WD, \tag{17}$$

$$L = L_{drawn} - 2LD. \tag{18}$$

V_a and V_b are the gate voltages and other symbols have their usual meaning. Figure 4 shows the MOS-C implementation of the circuit of Fig. 2.

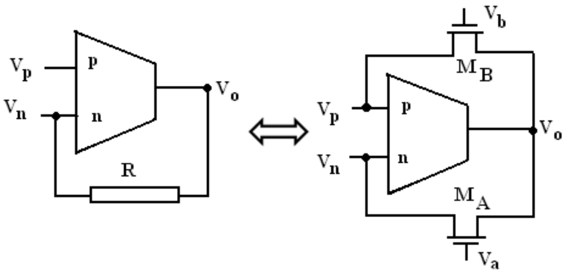


Fig. 3: MOS implementation of a linear resistance connected between negative terminal and the output.

3. Non-Ideality Analysis

The response of the filter may deviate due to non-ideality of OTRA in practice. Ideally the trans-resistance gain R_m is assumed to approach infinity. However, practically R_m is a frequency dependent finite value. Considering a single pole model for the trans-resistance gain, R_m can be expressed as

$$R_m(s) = \left(\frac{R_0}{1+s/\omega_0}\right), \tag{19}$$

where R_0 is low frequency transresistance gain. For high frequency applications, the transresistance gain, $R_m(s)$ reduces to

$$R_m(s) \approx \frac{1}{sC_p} \quad where \quad C_p = \frac{1}{R_0\omega_0}. \tag{20}$$

Taking this effect into account the transfer functions of the circuit of Fig. 3 modify to

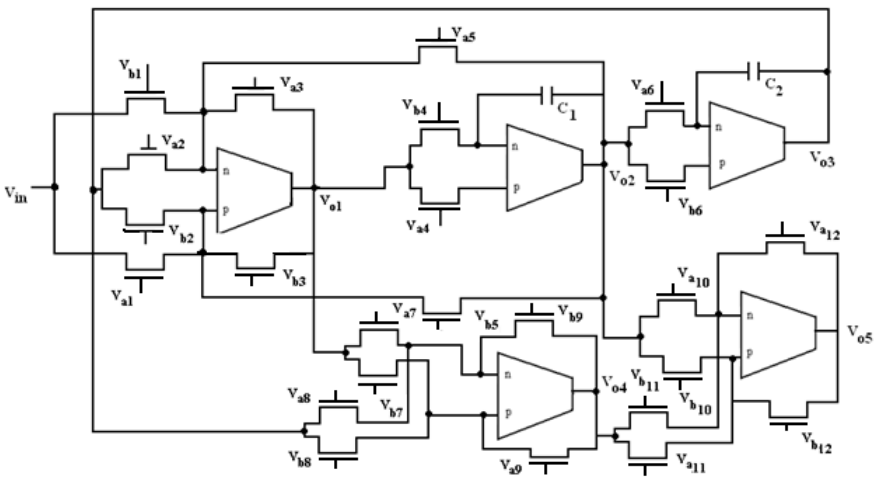


Fig. 4: OTRA MOS-C universal filter.

$$\left.\frac{V_{01}}{V_{in}}\right|_n = \frac{s^2 G_1 (C_1 + C_p)(C_2 + C_p)}{D_n(s)}, \tag{21}$$

$$\left.\frac{V_{02}}{V_{in}}\right|_n = \frac{s G_1 G_4 (C_2 + C_p)}{D_n(s)}, \tag{22}$$

$$\left.\frac{V_{03}}{V_{in}}\right|_n = \frac{G_1 G_4 G_6}{D_n(s)}, \tag{23}$$

$$\left.\frac{V_{04}}{V_{in}}\right|_n = \frac{G_1}{D_n(s)(G_9 + sC_p)} * (s^2 G_7 (C_1 + C_p)(C_2 + C_p) + G_4 G_6 G_8), \tag{24}$$

$$\left.\frac{V_{05}}{V_{in}}\right|_n = \frac{G_1}{D_n(s)(G_{12} + sC_p)} * \left((C_2 + C_p)(As^2 (C_1 + C_p) - G_4 G_{10}) + \frac{G_4 G_6 G_8 G_{11}}{(G_9 + sC_p)} \right), \tag{25}$$

where $A = \dfrac{G_7 G_{11}}{G_9 G_1}$ and

$$D_n(s) = s^2 (G_3 + sC_p)(C_1 + C_p)(C_2 + C_p) + sG_4 G_5 (C_2 + C_p) + G_2 G_4 G_6. \tag{26}$$

The effect of C_p can be eliminated by pre-adjusting the value of capacitors C_1 and C_2 and thus achieving self-compensation. The sC_p term appearing in parallel to G_i for i = 3, 9, 12 will result in the introduction of another pole having radian frequency as $\omega = 1/R_i C_p$. The smallest frequency of this newly introduced pole would occur for the largest value of R_i. The effect of this additional pole can be ignored by selecting the operating frequency range of the SIMO biquadratic universal filter much lower than pole frequency.

4. Simulation Results

The proposed SIMO biquadratic universal filter is verified through simulations using the CMOS implementation of the OTRA [3] as given in Fig. 5. The SPICE simulation was performed using 0,5 µm CMOS process parameters provided by MOSIS (AGILENT). Supply voltages taken are ±1,5 V. Aspect ratios for different transistors used in OTRA are given in Tab. 2. For simulations L_{drawn} and W_{drawn} are taken as 5 µm for all transistors used for resistance realization.

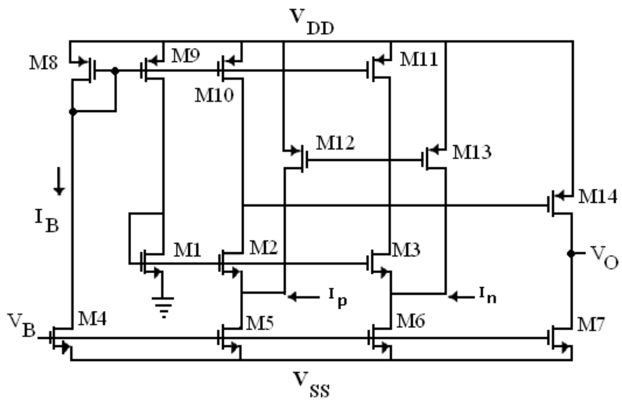
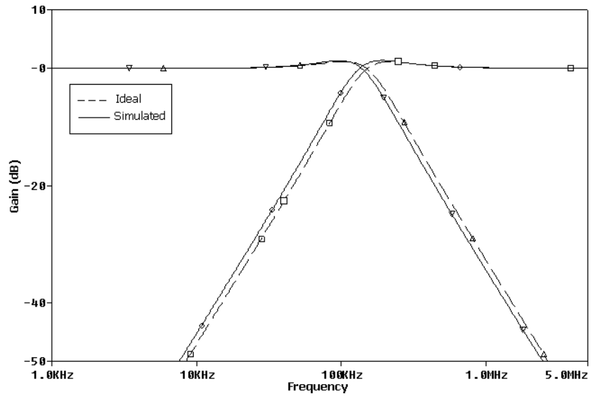


Fig. 5: CMOS implementation of OTRA [3].

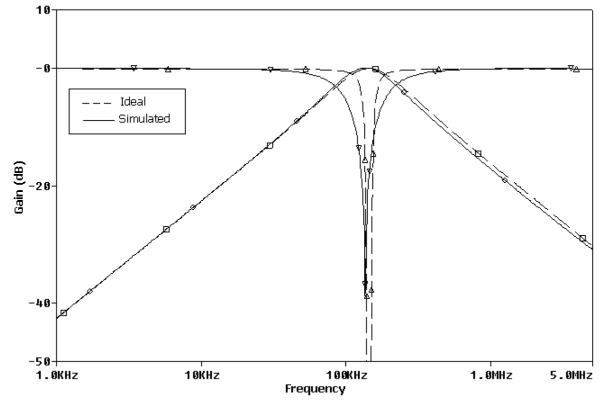
Tab.2: Aspect ratio of transistors used in OTRA.

Transistor	W(µm)/L(µm)
M1-M3	100/2,5
M4	10/2,5
M5,M6	30/2,5
M7	10/2,5
M8-M11	50/2,5
M12,M13	100/2,5
M14	50/0,5

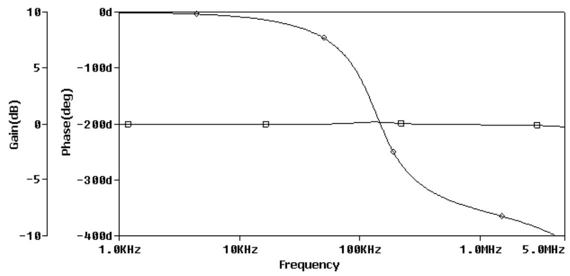
The proposed SIMO biquadratic universal filter as given in Fig. 4 is designed for the resonant frequency (f_0) of 120 kHz and Q_0=1 with component values C_1=C_2=100 pF and $R_i \approx$ 10,5 kΩ for i = 1, 2, . . . 12.



(a)



(b)



(c)

Fig. 6: Simulated frequency responses of the proposed circuit (a) low-pass and high-pass, (b) band-pass and notch, (c) all pass.

The value of R_i was set by taking the gate voltages as $V_{ai} = 1,4$ V and $V_{bi} = 0,75$ V for all i = 1, 2,. . . , 12. Figure 6 shows the simultaneously available frequency responses for low-pass, high-pass, band-pass, notch and allpass. The simulated resonant frequency is found to be in close agreement to the theoretical value. The orthogonal tunability of Q_0 with R_5 at $f_0 = 11,5$ kHz is shown in Fig. 7. This is obtained by selecting $C_1 = C_2 = 50$ pF, and $R_i = 272$ kΩ for i = 1,…, 4, 6,…,12 for different values of R_5. The values of Q_0 as obtained and gate bias voltages used for tuning of R_5 are listed in Tab. 3.

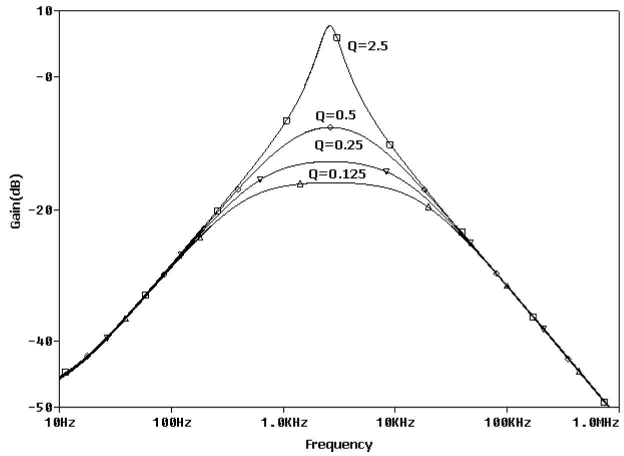


Fig. 7: Band-pass response for different Q_0 values.

Tab.3: Component values used for orthogonal tunability of Q_0.

S. No.	BiasVoltage V_{a5}(V)	Bias Voltage V_{b5}(V)	R_5(kΩ)	Q_0
1.	0,76	0,75	≈680	2,5
2.	0,80	0,75	≈136	0,5
3.	0,85	0,75	≈68	0,25
4.	0,95	0,75	≈34	0,125

The f_0 is electronically tunable by varying the gate voltage and is verified through simulations as depicted in Fig. 8. Values of f_0, for C_1=C_2 = 50 pF and $R_i \approx 23$ kΩ for i = 1,…3, 5,. . . , 12, along with different gate voltages chosen for varying R_4 are listed in Tab. 4.

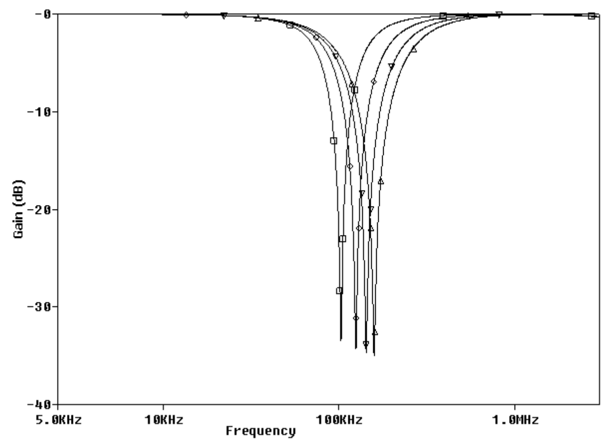


Fig. 8: Notch response for different ω_0 values.

Tab.4: Component values used to make f_0 electronically tunable.

S. No.	BiasVoltage V_{a4}(V)	Bias Voltage V_{b4}(V)	R_4(kΩ)	f_0 (kHz)
1.	1,1	0,9	≈34	113,8
2.	1,2	0,9	≈23	138,4
3.	1,3	0,9	≈17	160,0
4.	1,4	0,9	≈14	179,0

To study the time domain behavior of the BP filter three sinusoidal frequency components, a low frequency signal of 1 kHz, a high frequency component of 100 kHz and the third component is 11,5 kHz which is f_0 of the BP filter, are applied. The transient response of the filter circuit is shown in Fig. 9. It may be noted that the frequency components other than f_0 are significantly attenuated.

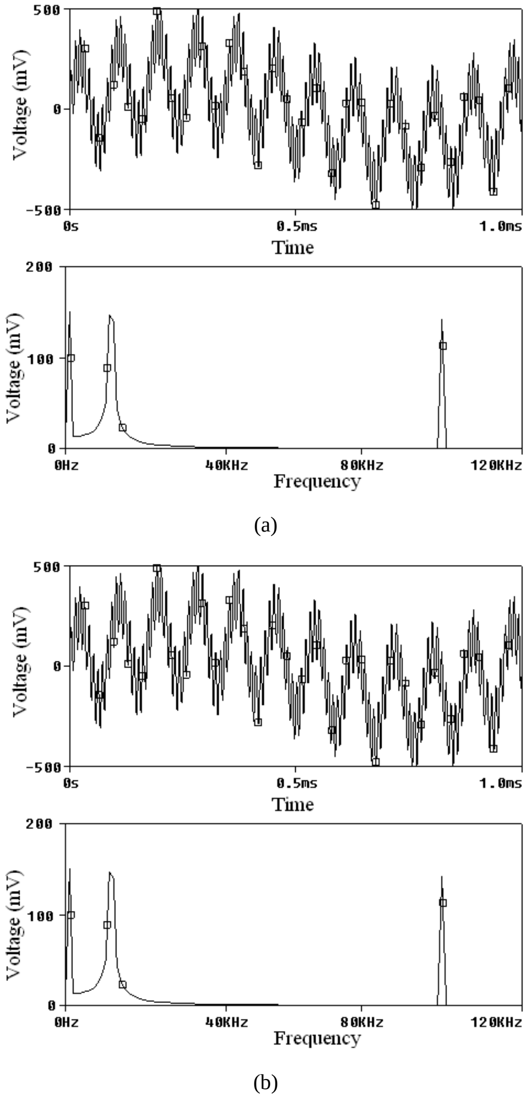


Fig. 9: Simulated transient response of BP filter. (a) Input signal and its frequency response (b) Output transient response and frequency spectrum.

To check the quality of the output of BP filter, the percentage total harmonic distortion (%THD) with the sinusoidal input signal is obtained as shown in Fig. 10. It is observed that the %THD remains considerably low [23] for input signal values till 70 mV. Simulated power consumption for the proposed universal filter is 4,04 mW.

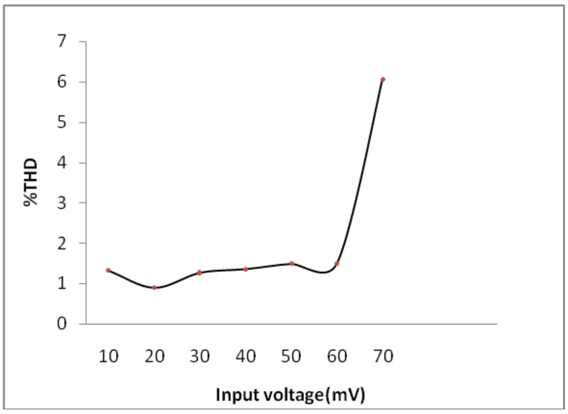


Fig. 10: THD variation with the input signal amplitude.

5. Conclusion

A new voltage-mode OTRA MOS-C universal biquadratic filter is presented which realizes all the standard filter functions simultaneously. The proposed circuit employs five OTRAs, two capacitors and twelve resistors. The filter possesses orthogonal and electronic tunability of filter parameters through MOS implemented resistors. The theoretical proposition is verified using PSPICE simulations.

References

[1] SALAMA, Khaled N. and Ahmed M SOLIMAN. CMOS operational transresistance amplifier for analog signal processing. *Microelectronics Journal*. 1999, vol. 30, iss. 3, pp. 235–245. ISSN 0026-2692. DOI: 10.1016/S0026-2692(98)00112-8.

[2] CHEN, J.-J., H.-W. TSAO and C.-C. CHEN. Operational transresistance amplifier using CMOS technology. *Electronics Letters*. 1992, vol. 28, iss. 22, pp. 2087-2088. ISSN 0013-5194. DOI: 10.1049/el:19921338.

[3] MOSTAFA, H. and A. M. SOLIMAN. A modified CMOS realization of the operational transresistance amplifier. *Frequenz*. 2006, vol. 60, iss. 3-4, pp. 70-77. ISSN 2191 -6349. DOI: 10.1515/FREQ.2006.60.3-4.70.

[4] ABEDELRAHMAN, K. K. and A. M. SOLIMAN. A modified CMOS differential OTRA. *International Journal of Electronics and Communication (AEU)*. 2009, vol. 63, iss. 12, pp. 1067-1071. ISSN 1434-8411. DOI: 10.1016/j.aeue.2008.08.003.

[5] DURUK, A., E. O. GUNES and H. KUNTMAN. A new low voltage CMOS differential OTRA for sub-micron technologies. *International Journal of Electronics and Communications (AEU)*. 2007, vol. 61, iss. 5, pp. 291-299. ISSN 1434-8411. DOI: 10.1016/j.aeue.2006.05.009.

[6] CAM, U., F. KACAR, O. CICEKOGLU, H. KUNTMAN and A. KUNTMAN. Novel grounded parallel immittance simulator topologies employing single OTRA. *International Journal of Electronics and Communications (AEU)*. 2003, vol. 57, iss. 4, pp. 287-290. ISSN 1434-8411. DOI: 10.1078/1434-8411-54100173.

[7] KILINC, S., K. N. SALAMA and U. CAM. Realization of fully Controllable negative Inductance with single operational Transresistance Amplifier. *Circuits Systems Signal Processing*.

2006, vol. 25, iss. 1, pp. 47-57. ISSN 1531-5878. DOI: 10.1007/s00034-004-0706-y.

[8] CAM, U., F. KACAR, O. CICEKOGLU, H. KUNTMAN and A. KUNTMAN. Novel two OTRA-based grounded immittance simulator topologies. *Analog Integrated circuit and Signal Processing*. 2004, vol. 39, no. 2, pp. 169-175. ISSN 0925-1030. DOI: 10.1023/B:ALOG.0000024064.73784.58.

[9] SALAMA, K.N. and A. M. SOLIMAN. Novel oscillators using operational transresistance amplifier. *Microelectronics Journal*. 2000, vol. 31, iss. 1, pp. 39-47. ISSN 0026-2692. DOI: 10.1016/S0026-2692(99)00087-7.

[10] CAM, U. A Novel Single-Resistance-Controlled Sinusoidal Oscillator Employing Single Operational Transresistance Amplifier. *Analog Integrated Circuits and Signal Processing*. 2002, vol. 32, no. 2, pp. 183-186. ISSN 0925-1030. DOI: 10.1023/A:1019586328253.

[11] PANDEY, R., N. PANDEY, M. BOTHRA and S. K. PAUL. Operational Transresistance Amplifier based Multiphase Sinusoidal Oscillator. *Journal of Electrical and Computer Engineering*. 2011, vol. 2011, ID 586853, pp. 1-8. ISSN 2090-0147. DOI: 10.1155/2011/586853.

[12] HOU, C.L., H. C. CHIEN and Y. K. LO. Squarewave generators employing OTRAs. *IEE proceedings.-Circuits Devices Systems*. 2005, vol. 152, no. 6, pp.718-722. ISSN 1350-2409. DOI: 10.1049/ip-cds:20045167.

[13] LO,Y. K., H. C. CHIEN and H. G. CHIU. Switch Controllable OTRA Based Bistable Multivibrator. *IET Circuits Devices Syst*. 2008 vol. 2, no. 4, pp. 373–382. ISSN 1751-8598. DOI: 10.1049/iet-cds:20080011.

[14] GOKCEN, A. and U. CAM. MOS-C single amplifier biquads using the operational transresistance amplifier. *International Journal of Electronics and Communications (AEU)*. 2009, vol. 63, iss. 8, pp. 660-664. ISSN 1434-8411. DOI: 10.1016/j.aeue.2008.05.008.

[15] SALAMA, K. N. and A. M. SOLIMAN. Active RC applications of the Operational Transresistance Amplifier. *Frequenz*. 2000, vol. 54, iss. 7-8, pp. 171-176. ISSN 2191-6349. DOI: 10.1515/FREQ.2000.54.7-8.171.

[16] CAKIR, C., U. CAM, U. and O. CICEKOGLU. Novel allpass filter configuration employing single OTRA. *IEEE Transactions on circuits and systems II: Express Briefs*. 2005, vol. 52, iss. 3, pp. 122-125. ISSN 1549-7747. DOI: 10.1109/TCSII.2004.842055.

[17] KILINC, S. and U. CAM. Cascadable allpass and notch filters employing single operational transresistance amplifier. *Computers and Electrical Engineering*. 2005, vol. 31, iss. 6, pp. 391-401. ISSN 0045-7906. DOI: 10.1016/j.compeleceng.2005.06.001.

[18] CHEN, J.-J., H.-W. TSAO and S.-I. LIU. Voltage -mode MOSFET–C filters using operational transresistance amplifiers (OTRAs) with reduced parasitic capacitance effect. *IEE Proceedings-Circuits Devices Systems*. 2001, vol. 148, iss. 5, pp. 242-249. ISSN 1350-2409. DOI: 10.1049/ip-cds:20010523.

[19] KILINC, S., A. U. KESKIN and U. CAM. Cascadable Voltage-Mode Multifunction Biquad Employing Single OTRA. *Frequenz*. 2007, vol. 61, iss. 3-4, pp.84-86. ISSN 2191-6349. DOI: 10.1515/FREQ.2007.61.3-4.84.

[20] CHANG, C.-M. KO, Y.-J.GUO, Z.-Y.LIN, Y.-T.HOU, C.-L. and HORNG, J.-W. Generation of voltage-mode OTRA-R/MOS-C LP, BP, HP, and BR biquad filter. In: *Proceedings of the 10th WSEAS international conference on Instrumentation, measurement, circuits and systems IMCAS'11*. Wisconsin: World Scientific and Engineering Academy and Society, 2011, pp. 28-34. ISBN 978-960-474-282-0.

[21] CHANG, C.-M. LIN, Y.-T.HSU, C.-K.HOU, C.-L. and HORNG, J.-W. Generation of Voltage-Mode OTRA-Based Multifunction Biquad Filter. In: *Proceedings of the 10th WSEAS international conference on Instrumentation, measurement, circuits and systems IMCAS'11*. Wisconsin: World Scientific and Engineering Academy and Society, 2011, pp. 21-27. ISBN 978-960-474-282-0.

[22] GOKCEN, A., S. KILINC and U. CAM. Fully integrated universal biquads using operational transresistance amplifiers with MOS-C realization. *Turkish Journal of Electrical Engineering and Computer Sciences*. 2011, vol. 19, no. 3, pp. 363-372. ISSN 1300-0632. DOI: 10.3906/elk-1002-416.

[23] ERDOGAN, E. S., R. O. TOPALOGLU, H. KUNTMAN and O. CICEKOGLU. New Current Mode Special Function Continuous - Time Active Filters Employing only OTAs and OPAMPs. *International Journal of Electronics*. 2004, vol. 91, no. 6, pp.345-359. ISSN 0020-7217. DOI: 10.1080/002072140410001695237.

About Authors

Rajeshwari PANDEY did B.Tech. (Electronics and Telecommunication) from University of Allahabad in 1988 and received her M.E (Electronics and Control) from BITS, Pilani, Rajasthan, India in 1992. Currently, she is Associate Professor in Department of Electronics and Communication Engineering, Delhi Technological University, Delhi. Her research interests include Analog Integrated Circuits, and Microelectronics.

Neeta PANDEY did M. E. in Microelectronics from Birla Institute of Technology and Sciences, Pilani, Rajasthan, India and Ph.D. from Guru Gobind Singh Indraprastha University Delhi, India. At present she is Associate Professor in Department of Electronics and Communication Engineering, Delhi Technological University, Delhi. A life member of ISTE, and member of IEEE, USA, she has published papers in International, National Journals of repute and conferences. Her research interests are in Analog and Digital VLSI Design.

Sajal Kumar PAUL did B.Tech., M.Tech., and Ph.D. in Radio Physics and Electronics from the Institute of Radio Physics and Electronics, University of Calcutta. He has served Webel Telecommunication Industries, Kolkata; Indira Gandhi National Open University (IGNOU), Kolkata; Advanced Training Institute for Electronics &Process Instrumentation (ATI-EPI), Hyderabad; North Eastern Regional Institute of Science & Technology (NERIST), Nirjuli and Delhi College of Engineering (DCE), Delhi in various capacities. He has served the Department of Electronics Engineering, Indian School of Mines, Dhanbad as Head of the Department and at present professor of the same department. His research interest includes Microelectronic Devices, Electronic Properties of Semiconductor and Bipolar and MOS Analog Integrated Circuits. He has more than 60 research publications in International and National journals of repute and conferences.

Ajay SINGH completed B. E. degree in June 2012 from Delhi Technological University, Delhi, India. His main research Interests include the field of analog circuit design and Signal processing. He has published few papers in National and International conferences/

journals.

Balamurali SRIRAM completed B. E. degree in June 2012,from Delhi Technological University, Delhi, India. His research interests include mixed signal circuit design and analog signal processing. Has also co-authored a journal and conference papers.

Kaushalendra TRIVEDI completed B. E. degree in June 2012 from Delhi Technological University, Delhi, India. His research interests include mixed signal circuit design and signal processing. Has also co-authored a journal and conference papers in current mode circuits.